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THE EFFECT OF MICROCRACKING IN MARTENSITE ON THE DEFORMATION AND FRACTURE BEHAVIOR OF FE-C ALLOYS AND COMMERCIAL STEELS

FINAL REPORT

BY

GEORGE KRAUSS

NOVEMBER 3, 1977

U.S. ARMY RESEARCH OFFICE

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The fracture pf hardened SAE/AISI 52100 steel was examined as a function of austenitizing and the early stages of tempering of the martensite in an Fe-1.22C alloy were examined as a function of tempering time and temperature. The fracture toughness of the 52100 steel was improved by the presence of residual proeutectiod carbides in specimens austenitized below Acm. Specimens austenitized above Acm showed increasing fracture toughness with increasing austenitizing temperature, a result explained by the initial crack extension

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during the fracture toughness test through the martensite-austenite microstructure of the grains rather than along the prior austenite grain boundaries as was observed on the balance of the overload fracture surface. Mössbauer examination of the Fe-1.22C martensite showed changes in the martensite, cementite and austenite components of the Mössbauer spectra as a function of tempering time and temperature and yielded evidence for transition carbide formation. Transmission electron microscopy verified the presence of the transition carbide, and showed it to be eta-carbide rather than epsilon-carbide.

THE EFFECT OF MICROCRACKING IN MARTENSITE ON THE DEFORMATION AND FRACTURE BEHAVIOR OF Fe-C ALLOYS AND COMMERCIAL STEELS

by

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Introduction

This report briefly describes the results of research performed in the period July 15, 1976 to July 14, 1977, the third year of effort on the research with the title given above. The first two years of research effort were spent at Lehigh University, Bethlehem, Pennsylvania, and the results of that work were presented in a FINAL REPORT, December 31, 1975, to the U.S. Army Research Office and the publications listed in that report.

Two areas received attention in the 1976/1977 research year: the fracture behavior of 52100 steel, and the early stages of tempering on an Fe-1.22C alloy. Each area will be described in seperate sections below. Also included are sections on the scientific personnel involved in the research and publications based on the results of the research.

Microstructure and Fracture of 52100 Steel

The fracture behavior of 52100 steel hardened and tempered to R_c 62 has been investigated as a function of austenitizing over the temperature range from 800 to 1100°C. Specimens were homogenized at 1150°C and either furnace cooled or isothermally transformed at 580°C to produce a pearlitic microstructure prior to austenitizing for hardening. Furnace-cooled specimens developed a proeutectoid carbide network that did not dissolve during subsequent austenitizing below A_{cm}. The residual proeutectoid carbides and the carbide-free martensite-austenite structure between them controlled fracture and produced K_{1c} of 19 $MPa \cdot m^{1/2}$, the highest determined in this investigation. The specimens isothermally transformed prior to austenitizing below A_{cm} produced the typical bearing microstructure of fine spherical carbides dispersed throughout a fine martensitic matrix and did not contain residual proeutectoid carbides. The transgranular fracture of the latter specimens by microvoid coalescence around the closely spaced spherical carbides resulted in the lowest values of fracture toughness, 14 to 16 $MPa \cdot m^{1/2}$, determined in these experiments. Austenitizing above A_{cm} caused solution of all carbides, a gradual coarsening of the austenitic grain size, a transition to plate martensite, and an increase in retained austenite. Fracture toughness increased slightly with increasing austenitizing temperature above A_{cm} despite the fact that fracture propagated primarily along the austenitic grain boundaries. The improved fracture toughness, verified by scanning electron microscopy of the fatigue crack-overload fracture interface, is believed to be caused in part by transgranular crack propogation during the first stages of crack extension that are most important in determining K_{1c}.

Early Stages of Tempering in an Fe-1.22C Alloy

The purpose of this portion of the research was to characterize as fully as possible the stage of tempering in a high carbon martensite where a transition carbide first begins to develop. An understanding of the formation of the transition carbide and its replacement by cementite is important with respect to explaining the low-temperature embrittlement that develops in association with the carbide replacement phenomenon.

Specimens of the Fe-1.22C alloy were austenitized at 950°C, brine quenched to form martensite, and tempered at 100°C, 150°C, 200°C, and 250°C for times between 15 min. and 16 hours. Mössbauer effect spectroscopy and transmission electron microscopy were used to follow the structural changes produced by tempering. The Mössbauer spectra were fixed with a superposition of either two or three magnetic 6-line components and a 3-line component. The magnetic components were produced by martensite, cementite, and, the transition carbide, while the 3-line component was due to the austenite.

Analysis of the Mössbauer spectra showed that the intensity of the 3-line resonance pattern produced by the retained austenite decreased with increasing tempering and was not evident after tempering 5 hours at 250°C, the tempering condition where the magnetic component of cementite became well established. The intensity associated with the central region of the Mössbauer spectra increased for certain tempering conditions despite the reduction of the retained austenite that also contributed to the intensity of the central region. This intensity increase was interpreted to be the result of the presence of small superparamagnetic particles that could correspond to the transition carbide. Other Mössbauer evidence for the transition carbide was the development of a magnetic subspectrum different from any of those associated with martensite. In particular, the new subspectrum had a weaker internal magnetic field, about 250kOc, than the 266kOc field associated with iron atoms with one carbon nearest neighbor and the 330kOc field associated with iron atoms with no carbon nearest neighbors.

The transmission electron microscopy confirmed the presence of the transition carbide in specimens that displayed the new intensity component of the Mössbauer spectra. Selected area diffraction analysis showed that the transition carbide corresponded to eta-carbide (Y. Hirotsu and S. Nagakura: Acta Met., 20, 1972, p. 645) rather than the epsilon carbide generally associated with the first stages of tempering of Fe-C martensite.

Personnel

The principal investigator of the grant research was Dr. George Krauss, AMAX Foundation Professor of Physical Metallurgy, Department of Metallurgical Engineers, Colorado School of Mines. Dr. Kozo Nakazawa, Principal Research Officer, National Research Institute for Metals, Tokyo, Japan served as post-doctoral research associate on the project and was active in all phases of the work. Dr. Don L. Williamson, Assistant Professor, Physics Department, Colorado School of Mines, performed the Mössbauer studies and data analysis in his laboratory.

List of Publications

1. K. Nakazawa and G. Krauss: "Microstructure and Fracture of 52100 Steel" submitted to Metallurgical Transactions, September 7, 1977. This work was also presented Oct. 25, 1977, at the 1977 TMS-AIME Fall Meeting in Chicago.

2. D. L. Williamson, K. Nakazawa, and G. Krauss: "Mössbauer Study of the Early Stages of Tempering in an Fe-1.22C Alloy". In preparation.